Technology-enabled Dematerialisation

BHM345 - Sustainability for Engineering

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Abstract

This case study discusses the potential for dematerialisation in modern and near-future society, enabled by advancements in manufacturing technology and necessitated by the dwindling number of available natural resources. The paper investigates the limitations of unsustainable growth, and explores the potential for reducing natural resource wastage through decentralising the product supply chain.

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1 Introduction

The pursuit of material wealth is intrinsic to the human condition. From the mythology of Ploutos and Dispater to the capitalist foundations of western society; the veneration of riches; and the American Dream founded on the principles of "Life, Liberty and the pursuit of happiness", the idea that one can be measured in some way by the qualities of their property is transcultural and almost universal of all societies.

As the population of the planet expands toward the seven billion people mark, the effects that our production and consumption of goods is taking on the environment is becoming undeniably apparent. Growth in many developing countries is increasing exponentially, with booms in the economies of China and India increasing the expendable incomes of their population. Markets are increasing in size and the expectations and consumption habits of many societies is driving towards a 'disposable society' of short lived, single purpose products, with a high percentage of waste.

It is clear that from an engineering perspective, this is an unsustainable model, and offers an unscalable solution. In this study, I will examine some of the potential implications of continued unrestricted growth, and explore some technological developments which could radically alter the way in which we consume goods without going into a level of technical detail that would alienate a causal reader. This paper aims to appeal to readers with an interest in sustainable growth and manufacturing technologies, posing a somewhat ethnocentric critique of consumption habits in the UK and US and presenting speculative solutions for some of the problems raised, based on hypothetical trends in current and near-future spending habits.

Coupled with the increase in consumer demand for goods is the large field of research and development that is focused on improving techniques for producing end-user goods. One of the most personally interesting subsets of this field is the school of research involved with developing consumer level 3D printing. The paper printer has utterly transformed the field of publishing and replaced the now obsolete typewriter with a more convenient means for quickly and repeatably publishing documents; in this study I will examine breakthroughs in 3D printing technology that could eventually enable home 3D printing to become an everyday and banal reality just like printing paper documents.

2 Literature Review

On the 11th of March 1986, Chuck Hull filed a patent for what he described as an *Apparatus for production of three-dimensional objects by stereolithography* [1]. This device used a stereolithographic processes to generate solid objects by printing successive layers of a thin material on top of each other to produce a finished shape. Now, 27 years later, the process now referred to as "3D printing" or "additive manufacturing" has been refined and developed enormously, and much has been written about it.

The majority of the technical details surrounding the additive manufacturing process will be spared in this study for fear of diluting the content; for a more involved treatise on the subject of additive manufacturing, see Gebhardt's *Understanding Additive Manufacturing* [2]. A retrospective history of the field of 3D printing can be found in Lipson and Kurman's *Fabricated* [3]. Chapman writes on the environmental benefits of using 3D printing to encourage repair over replacement in *Exploring 3D Printing and Sustainability* [4].

In the field of sustainability and engineering, Davim's *Sustainable Manufacturing* [5] offers a thorough analysis of improving ecological mindedness in the manufacturing of goods, and focuses heavily on reuse and recycling; however, his oversight around the field of additive manufacturing leaves something to be desired. *Advances in Sustainable Manufacturing* [6] offers a somewhat more forward thinking exploration into near-future technologies.

3 Growth in Consumption

Average global life expectancy has doubled in the last two centuries, with advancements in medical science, agriculture and industry enabling people to live longer and more comfortable lives [7]. Coupled with this is the wide diversity of work that people undertake, with the survival roles of food production and safety no longer being a necessity of all humans. The result is that more people have a greater amount of free time and expendable wealth at their disposal, and thus consumption increases, raising the quantity of materials and energy expended on non-survival tasks along with it. Figure 1 shows the non-linear relationship between the growth of wealth and population.

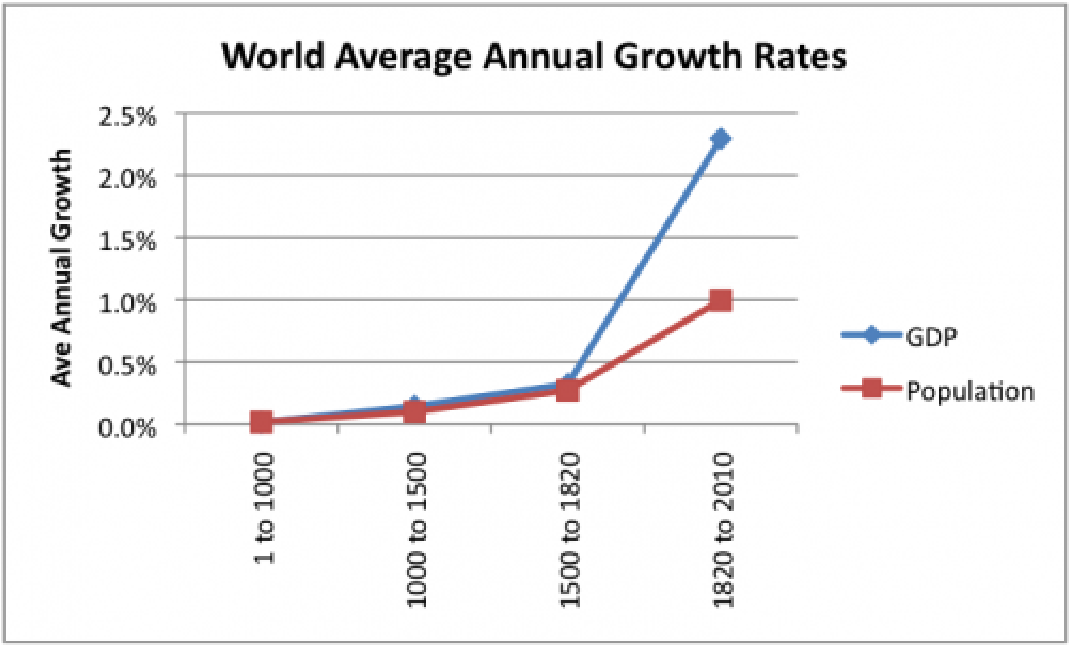

Figure 1: World Average Annual Growth Rates [8].

As with any finite system, unlimited growth is an impossibility, with the limiting factor being the availability of resources. In order to satisfy the long term goal of achieving a sustainable habitat for our species, we must curb our use of natural resources to match their availability. Unfortunately, the growth in the rate of consumerism shows no signs of reducing.

3.1 Mobile phones

There are few examples of the relentless growth of consumption greater than the mobile phone. Since the ownership of the devices have become so widespread (Figure 2), the market for handsets has become something of a global metric for our spending habits and rate of consumption.

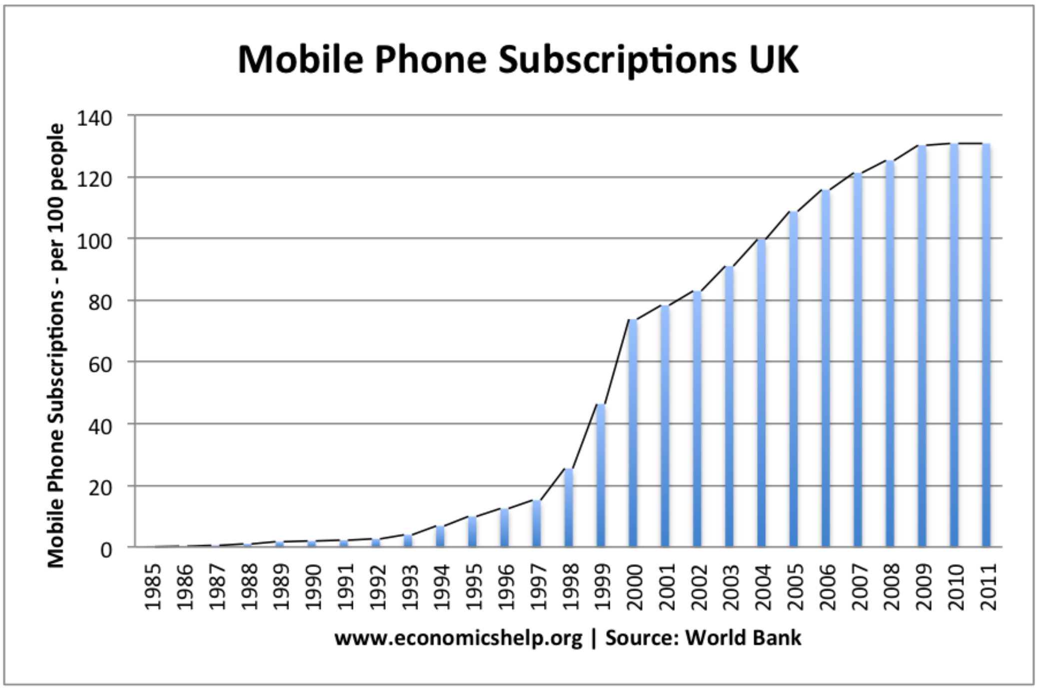

Figure 2: The number of mobile phone subscriptions per capita in the UK has exceeded 1.

A combination of heavy marketing and the ferocious rate of technological innovation in the sector has combined to make mobile phones a very short lived product. People purchase them, use them for a short amount of time and then quickly replace as they tire of it, or it is made obsolete. Table 1 shows the alarmingly short lifespan of the modern mobile phone.

Handset Replacement Cycle in Months

	2007	2008	2009	2010	Prepaid Subscriber	Income in PPP$
Brazil	51.5	74.2	70.4	80.8	80%	$11,239
Canada	29.5	30.8	31.8	33.0	20%	$39,057
Finland	41.8	58.1	74.5	74.5	14%	$34,585
France	28.5	28.8	29.9	30.8	30%	$34,077
Germany	43.7	55.8	49.5	45.7	55%	$36,033
India	322.1	144.0	185.6	93.6	96%	$3,339
Israel	67.1	56.1	67.0	76.5	53%	$29,531
Italy	53.3	43.1	42.9	51.5	87%	$29,392
Japan	25.6	35.2	43.0	46.3	1%	$33,805
Korea	27.3	25.1	24.2	26.9	0%	$29,836
Mexico	48.6	41.7	42.9	39.6	86%	$14,430
South Africa	52.3	118.6	46.3	38.2	80%	$10,498
United Kingdom	24.5	24.4	26.4	22.4	54%	$34,920
United States	18.7	19.6	21.1	21.7	22%	$47,284

Table 1: The average number of months between consumers replacing their handsets [9]

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Since mobile phones are bought almost exclusively new and at regular intervals, this translates into a huge demand on natural resources and the supply chain. Manufacturing a mobile phone is a costly process in environmental terms, and the stress that this places on resource gathering such as in rare earth metals is unsustainable [10]. Improvements must be made in the manufacturing process if consumption is going to continue at any appreciable rate.

4 Additive Manufacturing

4.1 Historical approaches to production

Historically, if you wanted to craft an object out of a given material, you had to obtain a block of that material larger than your desired object, and then use techniques such as drilling or cutting to remove bits of material until you achieve your finished result. This style of manufacturing is referred to as subtractive manufacturing, since you subtract material from one shape to produce another. This is always a wasteful process, with the efficiency being calculable based on the percentage of material wasted and the costs of the process used to perform the subtraction of materials.

4.2 The additive process

By contrast to subtractive manufacturing, the additive manufacturing process relies on incrementally building up material to make the finished object, requiring only enough material to produce the finished object.

Designing an object to be produced using additive manufacturing is a digital process. Computer Aided Design (CAD) tools are used to generate a digital 3D model which provides a perfect description of the desired object, to an infinite accuracy. This model is then computationally sliced into sections of a constant thickness determined by the printer and the material used, and the shape is aliased to within the precision of the printer. This is analogous to a cartographer using a fixed 10m scale to divide a map of the land into contours. Figure 3 shows an example model and sliced approximation next to it.

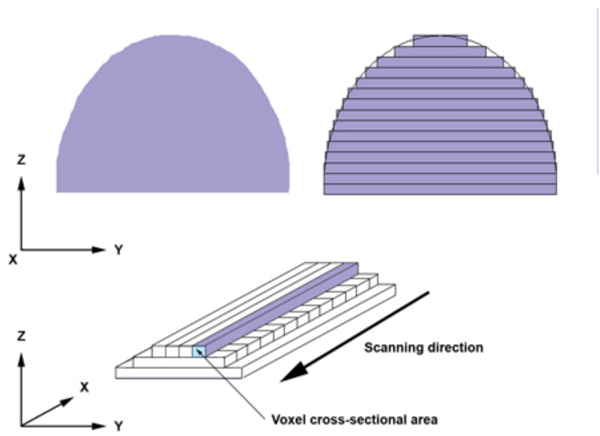

Figure 3: Horizontal slicing to produce an approximation for a model's shape (Materialgeeza, 2008. Creative Commons License).

Once computed and sliced, the 3D printer then goes about creating the object by layering one slice at a time onto a blank base until the finished object is created. The time taken to create the object depends on the speed of the printer and the number and size of the slices. Crucially, only the minimum amount of material is required, there is no wastage.

4.3 Material Wastage

To give a quantitative example of the improved efficiency of additive manufacturing, consider a hypothetical situation in which you would like to make a spherical object out of an unspecified material. A subtractive means of producing this sphere would be to obtain a cubic block of the material that is at least as large as the sphere's diameter in all three dimensions; Figure 4 demonstrates this. In the subtractive process, the cube would then be repeatedly chipped away at, starting at the corners and working towards a rounded shape, until reaching a spherical shape. For a sphere of radius r, the minimum required amount of materials can be shown to be:

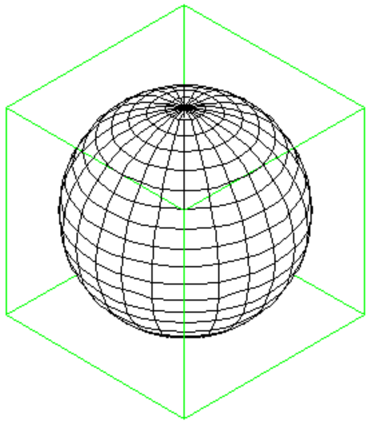

Figure 4: A sphere inside of a host cube of the smallest possible size.

$$V = a \times a \times a$$
$$V = a^3$$
$$a = 2r$$
$$V = (2r)^3$$
$$V = 8r^3$$

In an additive production, the amount of material required to produce the sphere is exactly equal to the volume of the sphere, with no wastage. This makes the required material equal to:

$$V = \frac{4}{3}\pi r^3$$

Since π approximates to 3.14, it is clear to see that the required materials are significantly reduced for the additive process. The difference in needed materials can be calculated to be:

$$V_{subtractive} = 8r^3$$
$$V_{additive} = \frac{4}{3}\pi r^3$$
$$8 = x(\frac{4}{3}\pi)$$
$$x = \frac{8}{\frac{4}{3}\pi}$$
$$x \approx \frac{8}{\frac{4}{3} \times 3.14}$$
$$x \approx \frac{8}{4.189}$$
$$x \approx 1.910$$

What this shows that the subtractive production process requires almost twice as much material to produce the same object as the additive process. This figure is unintuitvely high, but it demonstrates that to produce a solid sphere of diameter 1mtr, 4.2 m^3 of material is required in the additive production vs $8m^3$ for the subtractive equivalent, wasting almost enough material to construct a second sphere. On the scale of a mass produced product, this level of material wastage adds 90% to the raw materials cost.

Of course, the quantity of material wastage depends on the shape of the final desired object. As a real world example, Apple unveiled in 2008 that the latest range of their MacBook computers would have the bodies machined from a single block of aluminium [11]. This involves the subtractive process of removing material from a solid block of aluminium until the shape of a hollow laptop body is achieved. The material wastage for this process is much higher, with around 97% of the original aluminium block being removed. Fortunately, aluminium is easy to recycle to use again, but this process requires a huge amount of energy that would not be required if construction occurred in an additive rather than subtractive manner.

4.4 Market interest

As a result of the advantages that additive manufacturing offer over traditional methods, 3D printers have received more widespread interest in the past decade. As the technology matures and it becomes cheaper and it easier to produce these printers, general hype around the technology has increased. On the 19th of February 2013, WobbleWorks LLC. launched a fund-raising campaign to raise $30,000 to develop a pen which had 3D printing capabilities. A month later, $2,344,134 had been raised, all from voluntary donors who wanted to see the project come to fruition [12]. Similar success stories have been found elsewhere: re:3D raised $205,990 for their 3D printer project and Michael Lundwall raised $619,110 for a similar project. Today, many people are familiar with the 3D printing technology, although they may not have direct access to a printer themselves.

5 On Decentralised Production

5.1 The Fragility of the Supply Chain

There are further implications to the widespread adoption of additive manufacturing than just material waste. The traditional product supply chain involves manufacturers producing goods which are then distributed to retailers to be sold to customers. This means that authorities can track the ownership of items through the production and retail businesses, making it possible to trace items from creation to eventual owner. The spread of 3D printers into the consumer market brings with it challenges to the traditional supply chain that would not only deprecate the need for retailers, but also would also cast anonymity over the production of goods, as people gain the ability to produce their own property, at home, without the need to involve outside parties.

Furthering the problem of tracking production is the idea of the self-replicating printer. In 2004, Adrian Bowyer introduced the simple concept that if a 3D printer can be used to generate real world objects, then it could theoretically be used to generate a copy of itself. This idea was realised in the form of the RepRap printer [13], an additive manufacturing device which has the ability to print the majority of its own components. Bowyer encouraged the idea that a RepRap owner could print a copy for a friend, who in turn could then print copies for their friends, resulting in an exponential spread of the devices [14].

The implications of this self-replication are that it would become not only impossible to track the production of goods, but also impossible to track even who has the capabilities to produce these goods. At the moment, the traditional supply chain still applies to obtaining a 3D printer, so authorities can track their ownership by obtaining purchasing information from suppliers. In a world where obtaining a 3D printer requires simply asking a friend, then the decentralisation of the supply chain would be complete.

5.2 The "3D Gun"

It would be a grave oversight to write on the topic of additive manufacturing without taking at least a cursory glance at some of it's more controversial implications. Centred around the U.S. gun control debate, outspoken student Cody Wilson has received a large amount of media attention for launching what he calls the "Wiki Weapon" project, in which he is aiming to be the first person to create a 100% 3D printable gun, and to distribute the designs freely over the internet using Open Source licenses [15].

From the technical standpoint, the challenges faced in producing a printable gun are trivial. Consisting of a number of mechanical parts, the greatest limitation to the success of the project is the relatively low shock strength of the polymers used in the printing process of current commercial printers, but this is a problem which will be alleviated over time as printing heads become more sophisticated and durable.

The ethical issues raise by the idea of being able to print your own firearms are somewhat more intriguing. Currently, the United States Bureau of Alcohol, Tobacco, Firearms and Explosives (ATF) does not impose any regulations on a citizen manufacturing a gun for personal use, so hypothetical improvements in 3D printing technologies could result in people being able to print their own guns at home; combining this with the open and anonymous nature of the internet causes concern in many people who feel that this could result in making the firearms readily available for children and criminals.

Commenting on the Wiki Weapon site, software guru and "father" of Open Source Eric S. Raymond said *"I approve. Er, let me put it slightly differently: the guy who wrote the foundational papers on open source approves. This is the sort of thing that was *supposed* to happen as a second-order consequence"* [16]. This statement reveals a great deal about the intentions of the Open Source movement, making the debate one about the freedom of information. From that perspective, it is clear to see that attempts to quell the dissemination of information freely over the internet has failed, and so too would any attempts to prevent the widespread distribution of weapon designs.

6 Analysis and Conclusions

It is apparent that additive manufacturing technologies have the potential to destabilise the established traditional producer-consumer relationship that existed for so long. If people obtain the ability to manufacture goods at home, then the supply chain would be drastically and irreversibly restructured.

The field of additive manufacturing is emerging at too great a rate to make stable predictions about its future. What is clear though is that the current manufacturing processes will inevitably fail if not revolutionised in the way they consume natural resources. As the technology progresses, additive manufacturing and home 3D printing may well provide that revolution.

In the software industry, the only cost is in development, and distribution is free - once you have one copy of a piece of software, you can distribute it to create multiple copies. Home manufacturing could create a similar model for the consumption of everyday goods, as people need only distribute the blueprints for products, not the physical objects themselves - and in doing so, create a truly dematerialised society.

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